List of Publications

Brian W. Bush

Refereed Journals

C. Zhou, K. L. Summers, T. P. Caudell, K. Berkbigler, B. Bush, K. Davis, and S. Smith, "Graph Visualization for the Analysis of the Structure and Dynamics of Extreme-Scale Supercomputers," *J. Information Visualization* **3** (2004), p. 209-222.

> We are exploring the development and application of information visualization techniques for the analysis of new massively parallel supercomputer architectures. Modern supercomputers typically comprise very large clusters of commodity SMPs interconnected by possibly dense and often nonstandard networks. The scale, complexity, and inherent nonlocality of the structure and dynamics of this hardware, and the systems and applications distributed over it, challenge traditional analysis methods. As part of the *à la carte* team at Los Alamos National Laboratory, who are simulating these new architectures, we are exploring advanced visualization techniques and creating tools to enhance analysis of these simulations with intuitive 3D representations and interfaces. This work complements existing and emerging algorithmic analysis tools. This paper gives background on the problem domain, a description of a prototypical computer architecture of interest (on the order of 10,000 processors connected by a quaternary fat-tree communications network), and a presentation of three classes of visualizations that clearly display the switching fabric and the flow of information in the interconnecting network.

M. Blue and B. W. Bush, "Information Content in the Nagel-Schreckenberg Cellular Automata Traffic Model," *Phys. Rev.* **E 67** (2003), p. 047103.

> We compute the set dimension and find bounds for the set entropy of a cellular automaton model for multi-lane traffic. Set dimension and set entropy, which are measures of the information content per cell, are related to the fractal nature of the automaton and have practical implications for data compression. For models with maximum speed v_{max}, the set dimension is $[\log_2(v_{max} + 2)]^{-1}$, which is one bit per cell regardless of the maximum speed. For a typical maximum speed of five cells per time step, the dimension is approximately 0.356.

M. Blue, B. Bush, and J. Puckett, "Unified Approach to Fuzzy Graph Problems," *Fuzzy Sets and Systems* **125** (2002), pp. 355–368. *[cited 1 time]*

> We present a taxonomy of fuzzy graphs that treats fuzziness in vertex existence, edge existence, edge connectivity, and edge weight. Within that framework, we formulate some standard graph-theoretic problems (shortest paths, maximum flow, and minimum cut) for fuzzy graphs using a unified approach distinguished by its uniform application of guiding principles such as the construction of membership grades via the ranking of fuzzy numbers, the preservation of membership grade normalization, and the "collapsing" of fuzzy sets of graphs into fuzzy graphs. Finally, we provide algorithmic solutions to these problems, with examples.

J. P. S. van Schagen, Y. Alhassid, J. C. Bacelar, B. Bush, M. N. Harakeh, W. H. A. Hesselink, H. J. Hofmann, N. Kalantarnayestanaki, R. F. Noorman, A. J. M. Plompen, A. Stolk, Z. Sujkowski, and A. Vanderwoude, "GDR γ-Ray Decay in ^{156}Dy* from Regions Selected on Temperature and Angular Momentum," *Phys. Lett.* **B 343** (1995), pp. 64–68. *[cited 7 times]*

> The strength distribution of the GDR built on highly excited states in a restricted temperature domain in ^{156}Dy and ^{155}Dy nuclei has been deduced by subtraction of γ-ray spectra obtained for the decay of ^{154}Dy* and ^{156}Dy* from regions selected on angular momentum. The resulting difference spectra have been analyzed within the statistical model. The results show a large deformation ($|\beta|$ ~ 0.51 ± 0.29 and 0.35 ± 0.14) for the angular-momentum regions with $\langle J \rangle \sim 32\ \hbar$ at $T \approx 1.8 \pm 0.2$ MeV and $\langle J \rangle \sim 46\ \hbar$ at $T \approx 1.7 \pm 0.2$ MeV respectively, in satisfactory agreement with calculations performed in the framework of Landau theory of shape transitions and statistical fluctuations. The deduced centroid energies are in agreement with the systematics of the GDR built on the ground state. The width of the GDR shows a systematic increase with increasing temperature.

B. W. Bush and J. R. Nix, "Classical Hadrodynamics: A New Approach to Ultrarelativistic Heavy-Ion Collisions," in *Proc. 5th Int. Conf. on Nucleus-Nucleus Collisions, Taromina, Italy, 1994*, *Nucl. Phys.* **A583** (1995), pp. C705–C710. *[cited 1 time]*

We discuss a new approach to ultrarelativistic heavy-ion collisions based on classical hadrodynamics for extended nucleons, corresponding to nucleons of finite size interacting with massive meson fields. This new theory provides a natural covariant microscopic approach that includes automatically spacetime nonlocality and retardation, nonequilibrium phenomena, interactions among all nucleons; and particle production. In the current version of our theory, we consider N extended unexcited nucleons interacting with massive neutral scalar (σ) and neutral vector (ω) meson fields. The resulting classical relativistic many-body equations of motion are solved numerically without further approximation for soft nucleon-nucleon collisions at $P_{\rm lab}$ = 14.6, 30, 60, 100 and 200 GeV/c to yield the transverse momentum imparted to the nucleons. For the future development of the theory, the isovector pseudoscalar (π^+, π^-, π^0), isovector scalar (δ^+, δ^-, δ^0), isovector vector (ρ^+, ρ^-, ρ^0) and neutral pseudoscalar (η) meson fields that are known to be important from nucleon-nucleon scattering experiments should be incorporated. In addition, the effects of quantum uncertainty on the equations of motion should be included by use of techniques analogous to those used by Moniz and Sharp for nonrelativistic quantum electrodynamics.

B. W. Bush and J. R. Nix, "Classical Hadrodynamics: Application to Soft Nucleon-Nucleon Collisions," *Nucl. Phys.* **A560** (1993), pp. 586–602. *[cited 2 times]*

We present results for soft nucleon-nucleon collisions at $p_{\rm lab}$ = 14.6, 30, 60, 100 and 200 GeV/c calculated on the basis of classical hadrodynamics for extended nucleons. This theory, which corresponds to nucleons of finite size interacting with massive neutral scalar and vector meson fields, is the classical analogue of the quantum hadrodynamics of Serot and Walecka but without the assumptions of the mean-field approximation and of point nucleons. The theory is manifestly Lorentz-covariant and automatically includes space-time nonlocality and retardation, nonequilibrium phenomena, interactions among all nucleons and particle production when used for applications such as relativistic heavy-ion collisions. We briefly review the history of classical meson-field theory and present our classical relativistic equations of motion, which are solved to yield such physically observable quantities as scattering angle, transverse momentum, radiated energy and rapidity. We find that the theory provides a physically reasonable description of gross features associated with the soft reactions that dominate nucleon-nucleon collisions. The equations of motion are practical to solve numerically for relativistic heavy-ion collisions.

J. P. S. van Schagen, Y. Alhassid, J. C. Bacelar, B. Bush, M. N. Harakeh, W. H. A. Hesselink, H. J. Hofmann, N. Kalantarnayestanaki, R. F. Noorman, A. J. M. Plompen, A. Stolk, Z. Sujkowski, and A. Vanderwoude, "GDR Dissipation and Nuclear Shape in Hot Fast-Rotating Dy Nuclei," *Phys. Lett.* **B 308** (1993), pp. 231–236. *[cited 8 times]*

The statistical γ-ray decay of the GDR built on excited states in Dy nuclei has been investigated for selected domains of angular momentum up to about 70 $\hbar$ and temperatures in the range 1–2 MeV. The GDR strength distributions extracted from the data indicate large average nuclear deformations ($\beta \sim 0.35$) at high angular momentum and average temperatures $T \geq 1.5$ MeV. This experimental observation is supported by results from calculations in which thermal shape fluctuations are taken into account around an oblate equilibrium deformation $\beta_{\rm eq}$. Although this equilibrium deformation increases with angular momentum, the calculations show rather large and constant average deformations $\langle\beta\rangle \sim 0.35$.

Y. Alhassid and B. Bush, "Nuclear Level Densities in the Static Path Approximation: II. Spin Dependence in a Solvable Model," *Nucl. Phys.* **A565** (1993), pp. 399–426. *[cited 15 times]*

The static-path approximation (SPA) and mean-field approximation (MFA) for the partition function and level density are investigated with the inclusion of spin. The methods are studied within a solvable model, the nuclear SU(3) Elliot model. The SPA partition function is enhanced compared with the MFA partition function and is in good agreement with the exact result at all angular velocities (or spins) and at all but low temperatures. The error made in the SPA as well as in the saddle-point approximation used in the conversion from angular velocity to spin is only weakly dependent on the spin and is small at not too low temperatures (or excitation energies).

B. W. Bush and J. R. Nix, "Classical Hadrodynamics: Foundations of the Theory," *Ann. Phys.* **227** (1993), pp. 97–150. *[cited 5 times]*

We derive and discuss the classical relativistic equations of motion for an action corresponding to extended nucleons interacting with massive, neutral scalar and vector meson fields. This theory, which we call classical hadrodynamics, is the classical analogue of the quantum hadrodynamics of Serot and Walecka but without the assumptions of the mean-field approximation and of point nucleons. The theory is manifestly covariant and allows for non-equilibrium phenomena, interactions among all nucleons, and meson production when used for applications such as relativistic heavy-ion collisions. We review the history of classical meson field theory, with special emphasis on issues related to self-interaction, preacceleration, runaway solutions, and finite-size effects. Sample calculations are presented for nucleon-nucleon collisions at $p_{\rm lab}$ = 200 GeV/*c*, where we find that the theory provides a physically reasonable description of gross features associated with the dominating soft reactions. The equations of motion are practical to solve numerically for ultrarelativistic heavy-ion collisions.

Y. Alhassid and B. Bush, "Nuclear Level Densities in the Static Path Approximation: I. A Solvable Model," *Nucl. Phys.* **A549** (1992), pp. 43–58. *[cited 33 times]*

We investigate the static-path approximation (SPA) and mean-field approximation (MFA) for the level density within a solvable SU(2) model. Comparing the SPA level density to the MFA one, we find an enhancement with a great sensitivity to the interaction strength, in agreement with exact analytic results. This enhancement compensates for a corresponding suppression which occurs at negative temperatures. The saddle-point approximation used in converting the partition function to the level density works well at all but low energies.

B. W. Bush, G. F. Bertsch, and B. A. Brown, "Shape Diffusion in the Shell Model," *Phys. Rev.* **C 45** (1992), pp. 1709–1719. *[cited 37 times]*

The diffusion coefficient for quadrupolar shape changes is derived in a model based on the mixing of static Hartree-Fock configurations by the residual interaction. The model correctly predicts the width of single-particle configurations. We find a diffusion rate depending on temperature as T^3, consistent with at least one other theoretical estimate. However, our diffusion rate is an order of magnitude lower than two values extracted from data.

Y. Alhassid and B. Bush, "The Systematics of the Landau Theory of Hot Rotating Nuclei," *Nucl. Phys.* **A549** (1992), pp. 12–42. *[cited 8 times]*

The Landau theory of hot rotating nuclei, which was recently introduced to explain the universal features of the shape transitions, is shown to describe well many nuclei at moderate temperatures ($T >\approx$ 1 MeV) and spin. The Landau parameters are extracted from microscopic calculations. Their systematics as a function of temperature and neutron numbers is demonstrated for the neodymium isotopes with even number of neutrons. An extended Landau theory is introduced to describe better nuclei at lower temperatures and/or higher spins.

B. Bush and Y. Alhassid, "On the Width of the Giant Dipole Resonance in Deformed Nuclei," *Nucl. Phys.* **A531** (1991), pp. 27–38. *[cited 11 times]*

Applying surface dissipation models to the Goldhaber-Teller model, we calculate the dependence of the giant dipole resonance (GDR) width on the nuclear quadrupole deformation. When expressed in units of the spherical width, this width reduces to a purely geometrical elliptic integral. It is shown to be very well approximated by the empirical power law with an exponent of 1.6. This approach utilizes no free parameters and reproduces the experimentally observed width dependence for GDR's built on the ground state of heavy nuclei. The formula derived here plays an important role in a recently developed macroscopic approach to the GDR in hot rotating nuclei.

Y. Alhassid and B. Bush, "Effects of Orientation Fluctuations on the Angular Distribution of the Giant Dipole Resonance γ-Rays in Hot Rotating Nuclei," *Nucl. Phys.* **A531** (1991), pp. 39–62. *[cited 25 times]*

The macroscopic approach to the GDR in hot rotating nuclei is extended to include the angular distribution of the emitted GDR γ-rays. The effects of thermal shape fluctuation, and in particular fluctuations in the nuclear orientation with respect to the rotation axis, are discussed in the framework of the Landau theory. It is found that while orientation fluctuations have negligible effects on the GDR cross section, they cause significant attenuation in the angular anisotropy parameter a_2 which offsets the a_2 enhancement due to intrinsic shape fluctuations. It is shown that this fluctuation theory is

successful in reproducing both the observed cross section and a_2 in highly excited ^{90}Zr and ^{92}Mo compound nuclei. The non-adiabatic effects on a_2 are studied in terms of a time-dependent model for the quadrupole shape fluctuations.

Y. Alhassid and B. Bush, "Time-Dependent Fluctuations and the Giant Dipole Resonance in Hot Nuclei: Solvable Models," *Nucl. Phys.* **A531** (1991), pp. 1–26. *[cited 22 times]*

A recent macroscopic theory of time-dependent shape fluctuations in hot nuclei and their effects on the giant dipole resonance is investigated in the context of solvable models with one quadrupole shape degree of freedom. Using the framework of the Landau theory of shape transitions, both the quadrupole shape and the giant dipole degrees of freedom are described by a coupled set of stochastic equations. Two solvable models for which the dipole correlation function is found in closed form are discussed; one for a spherical nucleus and one for a deformed nucleus. The adiabatic and sudden limits of the models are examined. The latter limit is shown to produce a phenomenon known as motional narrowing. For the more general cases we introduce Monte Carlo techniques and test them against the solvable models.

B. Bush, G. Anno, R. McCoy, R. Gaj, and R. Small, "Fuel Loads in U. S. Cities," *Fire Tech.* **27** (1991), pp. 5–32.

Sources of burnable material within U.S. cities are analyzed. Based on a detailed evaluation of construction practices, storage of burnable contents, building function and layout, and density of buildings in city districts, we derive urban fuel load densities in terms of land use type and geographic location. Residential building fuel loads vary regionally from 123 to 150 kg/m^2; non-residential building classes have loads from 39 to 273 kg/m^2. The results indicate that average U.S. urban area fuel loads range from 14 to 21 kg/m^2.

Y. Alhassid and B. Bush, "Time-Dependent Shape Fluctuations and the Giant Dipole Resonance in Hot Nuclei: Realistic Calculations," *Nucl. Phys.* **A514** (1990), pp. 434–460. *[cited 27 times]*

The effects of time-dependent shape fluctuations on the giant dipole resonance (GDR) in hot rotating nuclei are investigated. Using the framework of the Landau theory of shape transitions we develop a realistic macroscopic stochastic model to describe the quadrupole time-dependent shape fluctuations and their coupling to the dipole degrees of freedom. In the adiabatic limit the theory reduces to a previous adiabatic theory of static fluctuations in which the GDR cross section is calculated by averaging over the equilibrium distribution with the unitary invariant metric. Nonadiabatic effects are investigated in this model and found to cause structural changes in the resonance cross section and motional narrowing. Comparisons with experimental data are made and deviations from the adiabatic calculations can be explained. In these cases it is possible to determine from the data the damping of the quadrupole motion at finite temperature.

Y. Alhassid and B. Bush, "Orientation Fluctuations and the Angular Distribution of the Giant Dipole Resonance γ Rays in Hot Rotating Nuclei," *Phys. Rev. Lett.* **65** (1990), pp. 2527–2530. *[cited 67 times]*

A recent macroscopic approach to the giant dipole resonances in hot rotating nuclei is extended to include the angular distributions of the γ rays emitted in the resonance decay. It provides a uniform description of thermal fluctuations in all quadrupole shape degrees of freedom within the framework of the Landau theory. In particular, the inclusion of fluctuations in the nuclear orientation with respect to the rotation axis is crucial in reproducing the observed attenuation of the angular anisotropy. The theory is applied to recent precision measurements in ^{90}Zr and ^{92}Mo and is the first to reproduce well both the observed giant-dipole-resonance cross sections and the angular anisotropies.

Y. Alhassid and B. Bush, "Effects of Thermal Fluctuations on Giant Dipole Resonances in Hot Rotating Nuclei," *Nucl. Phys.* **A509** (1990), pp. 461–498. *[cited 69 times]*

We present a macroscopic approach to giant dipole resonance (GDR) in highly excited nuclei, using a unified description of quadrupole shape thermal fluctuations. With only two free parameters, which are fixed by the zero-temperature nuclear properties, the model reproduces well experimental GDR cross sections in the $100 \leq A \leq 170$ mass range for both spherical and deformed nuclei. We also investigate the cross-section systematics as a function of both temperature and angular velocity and the sensitivity of the GDR peak to the nuclear shape. We conclude that at low temperatures ($T \approx 1$ MeV) the GDR cross section is sensitive to changes in the nuclear energy surface. Higher-temperature ($T >\approx 2$ MeV)

cross sections are dominated by large fluctuations (triaxial in particular) and are much less sensitive to the equilibrium shape.

Y. Alhassid and B. Bush, "Stochastic Approach to Giant Dipole Resonances in Hot Rotating Nuclei," *Phys. Rev. Lett.* **63** (1989), pp. 2452–2455. *[cited 40 times]*

A stochastic macroscopic approach to giant dipole resonances (GDR's) in hot rotating nuclei is presented. In the adiabatic limit the theory reduces to a previous adiabatic model where the unitary invariant metric is used to calculate equilibrium averages. Nonadiabatic effects cause changes in the GDR cross section and motional narrowing. Comparisons with experiments where deviations from the adiabatic limit are substantial are shown and can be used to determine the damping of the quadrupole motion at finite temperature.

R. D. Small, B. W. Bush, and M. A. Dore, "Initial Smoke Distribution for Nuclear Winter Calculations," *Aerosol Sci. and Tech.* **10** (1989), pp. 37–50. *[cited 3 times]*

Mappings showing the initial distribution of smoke from a 3000 MT strike against over 4000 targets in the United States are presented. An attack of this magnitude would attempt to deprive the United States of all military capabilities and to destroy its industrial capacity. Most urban areas would be affected and damage to the economic base would be substantial. Smoke distributions are derived for global climate model computation grids. Such distributions represent part of the initial conditions for a simulation of climate modification. A much finer grid (2×1.5 degree) mapping is also given. In the latter, mountain systems are resolved, and the possible influence of topography on smoke movement is discussed. Injection profiles determined from large area fire calculations show that the initial distribution and smoke mass centroid depend on the burning rate and fuel loading. Low fuel loadings or long burn times indicate a constant mixing ratio injection with a fairly low altitude centroid. A two-level constant mass density profile with a midtroposphere centroid is more appropriate for cities that burn rapidly or have higher combustible loadings. Wind patterns at a typical injection height indicate the effect of a nonuniform source on the initial global spread of smoke.

Y. Alhassid, B. Bush, and S. Levit, "Thermal Shape Fluctuations, Landau Theory, and Giant Dipole Resonances in Hot Rotating Nuclei," *Phys. Rev. Lett.* **61** (1988), pp. 1926–1929. *[cited 63 times]*

A macroscopic approach to giant dipole resonances (GDR's) in hot rotating nuclei is presented. It is based on the Landau theory of nuclear shape transitions and provides a unified description of thermal fluctuations in all quadrupole shape degrees of freedom. With all parameters fixed by the zero-temperature nuclear properties the theory shows a very good agreement with existing GDR measurements in hot nuclei. The sensitivity of the GDR peak to the shape of hot nuclei is critically examined. Low-temperature experimental results in Er show clear evidence for changes in the nuclear energy surface, while higher-temperature results are dominated by the fluctuations.

Y. Alhassid, B. Bush, and S. Levit, "Landau Theory of Shapes, Shape Fluctuations, and Giant Dipole Resonances in Hot Nuclei," *Nucl. Phys.* **A482** (1988), pp. C57–C64. *[cited 7 times]*

Universal features of evolution of the equilibrium nuclear shapes with temperature and angular momentum are predicted by the Landau theory of nuclear shape transitions. The general dependence of the nuclear free energy on the deformation given by this theory also provides a unified description of thermal fluctuations of all quadrupole degrees of freedom. Using this unified theory we calculate the giant dipole absorption by hot rotating nuclei and investigate its systematics as a function of nuclear spin and temperature. Direct comparison with experimental data is presented.

B. W. Bush and R. D. Small, "A Note on the Ignition of Vegetation by Nuclear Weapons," *Combust. Sci. and Tech.* **52** (1987), pp. 25–38. *[cited 1 time]*

Smoke produced from the ignition and burning of live vegetation by nuclear explosions has been suggested as a major contributor to a possible nuclear winter. In this paper, we consider the mechanics of live vegetation ignition by a finite-radius nuclear fireball. For specified plant properties, the amount of fireball radiation absorbed by a plant community is calculated as a function of depth into the stand and range from the fireball. The spectral regions of plant energy absorption and the overlap with the emitted fireball thermal spectra are discussed. A simple model for the plant response to the imposed thermal load is developed. First, the temperature is raised; the change depends on the leaf structure, moisture content, and plant canopy. Subsequent energy deposition desiccates the plant and finally raises its temperature to the threshold ignition limit. Results show the development of a variable depth ignition zone. Close to the fireball, ignition of the entire plant occurs. At greater distances (several

fireball radii) portions of the plant are only partially desiccated, and sustained burning is less probable. Far from the burst, the top of the stand is weakly heated, and only a small transient temperature change results. An estimate of the smoke produced by an exchange involving the U.S. missile fields shows that the burning of live vegetation only slightly increases the total nonurban smoke production.

R. D. Small and B. W. Bush, "Smoke Production from Multiple Nuclear Explosions in Nonurban Areas," *Science* **229** (1985), pp. 465–469. *[cited 12 times]*

The amount of smoke that may be produced by wildland or rural fires as a consequence of a large-scale nuclear exchange is estimated. The calculation is based on a compilation of rural military facilities, identified from a wide variety of unclassified sources, together with data on their geographic positions, surrounding vegetation (fuel), and weather conditions. The ignition area (corrected for fuel moisture) and the amount of fire spread are used to calculate the smoke production. The results show a substantially lower estimated smoke production (from wildland fires) than in earlier "nuclear winter" studies. The amount varies seasonally and at its peak is less by an order of magnitude than the estimated threshold level necessary for a major attenuation of solar radiation.

Conference Proceedings

Cheng Zhou, Kenneth L. Summers, Thomas P. Caudell, Kathryn Berkbigler, Brian Bush, Kei Davis, and Steve Smith, "Graph Visualization for the Analysis of the Structure and Dynamics of Extreme-Scale Supercomputers," in *ACM Symposium on Software Visualization San Diego, California, 11–13 June 2003*, pp. 143–149.

We are exploring the development and application of information visualization techniques for the analysis of new massively parallel supercomputer architectures. Modern supercomputers typically comprise very large clusters of commodity SMPs interconnected by possibly dense and often nonstandard networks. The scale, complexity, and inherent nonlocality of the structure and dynamics of this hardware, and the systems and applications distributed over it, challenge traditional analysis methods. As part of the *à la carte* team at Los Alamos National Laboratory, who are simulating these advanced architectures, we are exploring advanced visualization techniques and creating tools to provide intuitive exploration, discovery, and analysis of these simulations. This work complements existing and emerging algorithmic analysis tools. This paper gives background on the problem domain, a description of a prototypical computer architecture of interest (on the order of 10,000 processors connected by a quaternary fat-tree communications network), and a presentations of two classes of visualizations that clearly display the switch structure and the flow of information in the interconnecting network.

Kathryn Berkbigler, Graham Booker, Brian Bush, Kei Davis, and Nicholas Moss, "Simulating the Quadrics Interconnection Network," in *HPC2003: High Performance Computing Symposium 2003, Advance Simulation Technologies Conference 2003, Orlando, Florida, 30 March–3 April 2003. [cited 1 time]*

We outline *à la carte*, an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations, and describe in detail our simulation model of the Quadrics interconnection network. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc., with disparate resolutions and fidelities, into an integrated simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. Simple ping timings can be modeled to approximately 100 ns. We present results comparing the simulated versus actual execution time of a 3D neutron transport application run on a machine with a Quadrics network.

Kathryn Berkbigler, Brian Bush, Kei Davis, Nicholas Moss, Steve Smith, Thomas P. Caudell, Kenneth L. Summers, and Cheng Zhou, "*À la carte*: A Simulation Framework for Extreme-Scale Hardware Architectures," in *MS 2003: IASTED International Conference on Modelling and Simulation, Palm Springs, California, 24–26 February 2003. [cited 1 time]*

We outline *à la carte*, an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc., with disparate resolutions, into an integrated

simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. The current implementation includes low- and medium-fidelity models of the network and low-fidelity and direct execution models of the workload. It supports studies of both simulation performance and scaling, and the properties of the simulated system themselves.

C. Unal, B. Bush, K. Werley, and P. Giguere, "Modeling of Interdependent Infrastructures," in *PSAM6: International Conference on Probabilistic Safety Assessment and Management, San Juan, Puerto Rico, 23–28 June 2002*.

An actor-based modeling methodology is used to simulate interactions among interdependent commercial infrastructures. The goal of this method is to capture the complex, nonlinear, self-organizing, emergent, and sometimes chaotic behaviors and interactions exemplified by complex systems, rather than relying on traditional aggregate mathematical and simulation techniques. A prototype model of four interdependent infrastructures was considered as an example. The actor-based definitions of the electric-power transmission line and natural-gas pipeline networks were developed to realistically simulate the dynamic interactions within each of these infrastructures and the interactions and interdependencies between these two infrastructures. A three-dimensional representation of system components and interconnectivity was developed. The visualization is an interactive, three-dimensional, geographically based, "layered" view of infrastructure interdependencies. It also links to a geographic information system for data analysis. A unique iterative natural-gas network solver algorithm was developed. Our assessment shows that a hybrid approach using an actor-based definition of infrastructure components in conjunction with iterative and commercial solvers has great promise for addressing the operation of interdependent infrastructures in a restructured and deregulated environment.

Francis Alexander, Kathryn Berkbigler, Graham Booker, Brian Bush, Thomas Caudell, Kei Davis, Tim Eyring, Adolfy Hoisie, Donner Holten, Steve Smith, and Kenneth Summers, "Extreme-Scale Architecture Simulation," *SC'2001 Research Poster Session, Denver, Colorado, 10–16 November 2001*.

C. L. Barrett, B. W. Bush, S. Kopp, H. S. Mortveit, and C. M. Reidys, "Sequential Dynamical Systems and Applications to Simulations," in *Proc. Advanced Simulation Technologies Conference (ASTC 2000), Washington D.C., April 16–20, 2000*.

Computer simulations are extensively used for business and science applications. However, a simulation generically generates a certain class of dynamical system whose properties are poorly understood. In this paper we will address theoretical issues on computer simulations and illustrate our concepts for the simulation of circular one-lane traffic. We propose a certain class of discrete dynamical systems (SDS) that captures key features of computer simulations and then show how SDS techniques can be applied in a case of infrastructure simulations.

B. W. Bush and J. R. Nix, "Particle-Production Mechanism in Relativistic Heavy-Ion Collisions," in *Proc. 7th Int. Conf. on Nuclear Reaction Mechanism, Varenna, Italy, 1994* (Milan: Università degli Studi di Milano, 1994), p. 592. *[cited 1 time]*

We discuss the production of particles in relativistic heavy-ion collisions through the mechanism of massive bremsstrahlung, in which massive mesons are emitted during rapid nucleon acceleration. This mechanism is described within the framework of classical hadrodynamics for extended nucleons, corresponding to nucleons of finite size interacting with massive meson fields. This new theory provides a natural covariant microscopic approach to relativistic heavy-ion collisions that includes automatically spacetime nonlocality and retardation, nonequilibrium phenomena, interactions among all nucleons, and particle production. Inclusion of the finite nucleon size cures the difficulties with preacceleration and runaway solutions that have plagued the classical theory of self-interacting point particles. For the soft reactions that dominate nucleon-nucleon collisions, a significant fraction of the incident center-of-mass energy is radiated through massive bremsstrahlung. In the present version of the theory, this radiated energy is in the form of neutral scalar (σ) and neutral vector (ω) mesons, which subsequently decay primarily into pions with some photons also. Additional meson fields that are known to be important from nucleon-nucleon scattering experiments should be incorporated in the future, in which case the radiated energy would also contain isovector pseudoscalar (π^+, π^-, π^0), isovector scalar (δ^+, δ^-, δ^0), isovector vector (ρ^+, ρ^-, ρ^0), and neutral pseudoscalar (η) mesons.

B. W. Bush and J. R. Nix, "Classical Hadrodynamics for Extended Nucleons," in *Proc. 8th Winter Workshop on Nuclear Dynamics, Jackson Hole, Wyoming, 1992* (Singapore: World Scientific, 1992), pp. 311–316. *[cited 3 times]*

> We discuss a new approach to relativistic nucleus-nucleus collisions based on classical hadrodynamics for extended nucleons, corresponding to nucleons of finite size interacting with massive meson fields. This theory provides a natural covariant microscopic approach to relativistic nucleus-nucleus collisions that includes automatically spacetime nonlocality and retardation, nonequilibrium phenomena, interactions among all nucleons, and particle production. Inclusion of the finite nucleon size cures the difficulties with preacceleration and runaway solutions that have plagued the classical theory of self-interacting point particles.

B. W. Bush and J. R. Nix, "Calculations of Ultrarelativistic Nucleus-Nucleus Collisions Based on Classical Hadrodynamics for Extended Nucleons," in *Contributed Papers and Abstracts, Quark Matter '91, Ninth Int. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions, Gatlinburg, Tennessee, 1991* (n.c.: n.p., 1991), p. T98. *[cited 3 times]*

B. W. Bush, J. R. Nix, and A. J. Sierk, "Classical Hadrodynamics Approach to Ultrarelativistic Heavy-Ion Collisions," in *Proc. 4th Conf. on the Intersections between Particle and Nuclear Physics, Tucson, Arizona, 1991, AIP Conference Proceedings* **243** (New York: American Institute of Physics, 1992), pp. 835–837. *[cited 3 times]*

> We discuss the exact solution of the classical relativistic equations of motion for an action corresponding to nucleons interacting with massive scalar and vector meson fields. This model—the classical analogue of the quantum hadrodynamics of Serot and Walecka—provides a manifestly Lorentz covariant approach to heavy-ion collisions, allows for nonequilibrium phenomena, interactions of correlated nucleon clusters, and particle production, and is valid when interaction times are short. We present an analysis of the nonlocality inherent in the model and discuss effects arising from the finite size of a nucleon.

B. W. Bush, J. R. Nix, and A. J. Sierk, "Spacetime Nonlocality and Retardation in Relativistic Heavy-Ion Collisions," in *Advances in Nuclear Dynamics, Proc. 7th Winter Workshop on Nuclear Dynamics, Key West, Florida, 1991* (Singapore: World Scientific, 1991), pp. 282–287. *[cited 3 times]*

> We discuss the exact numerical solution of the classical relativistic equations of motion for a Lagrangian corresponding to point nucleons interacting with massive scalar and vector meson fields. The equations of motion contain both external retarded Lorentz forces and radiation-reaction forces; the latter involve nonlocal terms that depend upon the past history of the nucleon in addition to terms analogous to those of classical electrodynamics. The resulting microscopic many-body approach to relativistic heavy-ion collisions is manifestly Lorentz covariant and allows for nonequilibrium phenomena, interactions with correlated clusters of nucleons, and particle production. For point nucleons, the asymptotic behavior of nucleonic motion prior to the collision is exponential, with a range in proper time of approximately 0.5 fm. However, this behavior is altered by the finite nucleon size, whose effect we are currently incorporating into our equations of motion. The spacetime nonlocality and retardation that will be present in the solutions of these equations may be responsible for significant collective effects in relativistic heavy-ion collisions.

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Francis J. Alexander, Marian Anghel, Kathryn Berkbigler, Graham Booker, Brian Bush, Kei Davis, Adolfy Hoisie, Nicholas Moss, Steve Smith, Thomas P. Caudell, Donald P. Holten, Kenneth L. Summers, and Cheng Zhou, "Design, Implementation, and Validation of Network and Workload Simulations for a 30-TeraOPS Computer System," (Los Alamos National Laboratory, 2003).

> The magnitude of the scientific computations targeted by the US DOE ASCI project requires as-yet unavailable computational power, and unprecedented bandwidth to enable remote, realtime interaction with the compute servers. To facilitate these computations ASCI plans to deploy massive computing platforms, possibly consisting of tens of thousands of processors, capable of achieving 10-100 TeraOPS, with WAN connectivity from these to distant sites. For various reasons the current approach to building a yet-larger supercomputer—connecting commercially available SMPs with a network—may be reaching practical limits. Better hardware design and lower development costs require performance evaluation, analysis, and modeling of parallel applications and architectures, and in particular predictive capability. We outline an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations, and describe our progress in its realization. The simulation environment is intended to allow (i) exploration of hardware/architecture design space; (ii) exploration of algorithm/implementation space both at the application level (e.g. data distribution and communication) and the system level (e.g. scheduling, routing, and load balancing); (iii) determining how application performance will scale with the number of processors or other components; (iv) analysis of the tradeoffs between performance and cost; and (v) testing and validating analytical models of computation and communication. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc. with disparate resolutions, into an integrated simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. Our current implementation, includes low and medium-fidelity models of the network and low-fidelity and direct execution models of the workload. It supports studies of both simulation performance and scaling, and the properties of the simulated system themselves. Ongoing work allows more realistic simulation and dynamic visualization of ASCI-like workloads on very large machines.

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The magnitude of the scientific computations targeted by the US DOE ASCI project requires as-yet unavailable computational power, and unprecedented bandwidth to enable remote, realtime interaction with the compute servers. To facilitate these computations ASCI plans to deploy massive computing platforms, possibly consisting of tens of thousands of processors, capable of achieving 10-100 TeraOPS, with WAN connectivity from these to distant sites. For various reasons the current approach to building a yet-larger supercomputer—connecting commercially available SMPs with a network—may be reaching practical limits. Better hardware design and lower development costs require performance evaluation, analysis, and modeling of parallel applications and architectures, and in particular predictive capability. We outline an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations, and describe our progress in its realization. The simulation environment is intended to allow (i) exploration of hardware/architecture design space; (ii) exploration of algorithm/implementation space both at the application level (e.g. data distribution and communication) and the system level (e.g. scheduling, routing, and load balancing); (iii) determining how application performance will scale with the number of processors or other components; (iv) analysis of the tradeoffs between performance and cost; and (v) testing and validating analytical models of computation and communication. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc. with disparate resolutions, into an integrated simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. Our current implementation, includes low and medium-fidelity models of the network and low-fidelity and direct execution models of the workload. It supports studies of both simulation performance and scaling, and the properties of the simulated system themselves. Ongoing work allows more realistic simulation and dynamic visualization of ASCI-like workloads on very large machines.

Francis J. Alexander, Kathryn Berkbigler, Graham Booker, Brian Bush, Kei Davis, Adolfy Hoisie, Steve Smith, Thomas P. Caudell, Donald P. Holten, Kenneth L. Summers, and Cheng Zhou, "Design and Implementation of Low- and Medium-Fidelity Network Simulations of a 30-TeraOPS System," Report LA-UR-02-1930 (Los Alamos National Laboratory, 2002).

The magnitude of the scientific computations targeted by the ASCI project requires as-yet unavailable computational power. To facilitate these computations ASCI plans to deploy massive computing platforms, possibly consisting of tens of thousands of processors, capable of achieving 10-100 TeraOPS. For various reasons the current approach to building a yet-larger supercomputer—connecting commercially available SMPs with a network—may be reaching practical limits. The path to better hardware design and lower development costs involves performance evaluation, analysis, and modeling of parallel applications and architectures, and in particular predictive capability. We outline an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations. The proposed simulation environment can be used for: (i) exploration of hardware/architecture design space; (ii) exploration of algorithm/implementation space both at the application level (e.g. data distribution and communication) and the system level (e.g. scheduling, routing, and load balancing); (iii) determining

how application performance will scale with the number of processors or other components; (iv) analysis of the tradeoffs between performance and cost; and, (v) testing and validating analytical models of computation and communication. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc., with disparate resolutions, into an integrated simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. Our initial implementation, comprising low- and medium-fidelity models for the network and a low-fidelity model for the workload, can simulate at least 4096 computational nodes in a fat-tree network using Quadrics hardware. It supports studies of both simulation performance and scaling, and the properties of the simulated system themselves. Ongoing work allows more realistic simulation and visualization of ASCI-like workloads on very large machines.

Kathryn Berkbigler, Brian Bush, Kei Davis, Adolfy Hoisie, Steve Smith, Cheng Zhou, Kenneth Summers, and Thomas Caudell, "Graph Visualization for the Analysis of the Structure and Dynamics of Extreme-Scale Supercomputers," Report LA-UR-02-1929 (Los Alamos National Laboratory, 2002).

We are exploring the development and application of information visualization techniques for the analysis of new extreme-scale supercomputer architectures. Modern super-computers typically comprise very large clusters of commodity SMPs interconnected by possibly dense and often nonstandard networks. The scale, complexity, and inherent nonlocality of the structure and dynamics of this hardware, and the systems and applications distributed over it, challenge traditional analysis methods. As part of the *à la carte* team at Los Alamos National Laboratory, who are simulating these advanced architectures, we are exploring advanced visualization techniques and creating tools to provide intuitive exploration, discovery, and analysis of these simulations. This work complements existing and emerging algorithmic analysis tools. Here we gives background on the problem domain, a description of a prototypical computer architecture of interest (on the order of 10,000 processors connected by a quaternary fat-tree network), and presentations of several visualizations of the simulation data that make clear the flow of data in the interconnection network.

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B. W. Bush, C. R. Files, and D. R. Thompson, “Empirical Characterization of Infrastructure Networks,” Report LA-UR-01-5784 (Los Alamos National Laboratory, 2001).

Critical infrastructure protection is a recognized problem of national importance. Infrastructure networks such as electric power, natural gas, communications, and transportation systems have an inherent graph-theoretic structure. Quantitatively characterizing the essential properties of infrastructure networks for various domains lays a valuable foundation for studying the universal features (especially criticality, robustness, etc.) and specific characteristics of such networks. We construct an extensive reference data set of infrastructure network graphs: 44 graphs of 13 types with nearly one million vertices and over one million edges. After regularizing these graphs, we compute more than fifty metrics related to connectivity, distance scale, cyclicity, cliquishness, and redundancy. We contrast these metrics for different types of infrastructures, study their interrelationship, and use them to cluster and classify systems. We consider both intact networks and networks that have been degraded by the removal of some vertices or edges either at random or systematically—this provides insight as to the robustness of the network if it were subject to a natural disaster or an attack.

C. Unal, K. Werley, P. Giguere, B. Bush, and R. Gordon, “Energy Interdependence Simulation,” Report LA-UR-01-5297 (Los Alamos National Laboratory, 2001).

Francis J. Alexander, Kathryn Berkbigler, Graham Booker, Brian Bush, Kei Davis, and Adolfy Hoisie, “An Approach to Extreme-Scale Simulation of Novel Architectures,” Report LA-UR-01-4087 (Los Alamos National Laboratory, 2001).

We outline an approach for simulating computing architectures applicable to extreme-scale systems (thousands of processors) and to advanced, novel architectural configurations. We believe that simulation is the predictive tool of choice for evaluating the performance of such systems. Our component-based design allows for the seamless assembly of architectures from representations of workload, processor, network interface, switches, etc., with disparate resolutions into an integrated simulation model. This accommodates different case studies that may require different levels of fidelity in various parts of a system. Our initial prototype, comprising low-fidelity models of workload and network, aims to model at least 4096 computational nodes in a fat-tree network. It supports studies of simulation performance and scaling rather than the properties of the simulated system themselves. Future work will allow more realistic simulation and visualization of ASCI-like workloads on very large machines.

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This report outlines recent work implementing and calibrating actuated traffic controls and vehicle detectors in TRANSIMS. We have developed a generic control that provides a flexible approach to representing such devices. Although not modeled upon specific existing hardware or algorithms, our implementation provides a responsive control over a wide variety of demand conditions.

R. J. Beckman, B. W. Bush, K. M. Henson, and P. E. Stretz, “Portland Study Synthetic Population,” Report LA-UR-01-4610 (Los Alamos National Laboratory, 2001).

TRANSIMS (Transportation Analysis and Simulation System) is an integrated system of travel forecasting models designed to give transportation planners accurate, complete information on traffic impacts, congestion, and pollution. The Population Synthesizer Module constructs a regional population imitation with demographics closely matching the real population. Households are distributed spatially to approximate regional population distribution. The synthetic populationÂ’s demographics form basis for individual and household activities requiring travel and their household locations determine some of the travel origins and destinations. This report outlines how we have constructed the synthetic population for our Portland, Oregon, case study. It also briefly summarizes the characteristics of the data, and how we verified that the data was correctly generated.

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C. L. Barrett, K. B. Berkbigler, K. R. Burris, B. W. Bush, S. D. Hull, J. M. Hurford, P. Medvick, D. A. Kubicek, M. Marathe, J. D. Morgeson, K. Nagel, D. J. Roberts, L. L. Smith, M. J. Stein, P. E. Stretz, S. J. Sydoriak, K. Cervenka, M. Morris, and R. Donnelly, "The Dallas-Ft. Worth Case Study," Report LA-UR-97-4502 (Los Alamos National Laboratory, 1997).

M. Blue, B. Bush, and J. Puckett, "Applications of Fuzzy Logic to Graph Theory," Report LA-UR-96-4792 (Los Alamos National Laboratory, 1997).

> Graph theory has numerous applications to problems in systems analysis, operations research, transportation, and economics. In many cases, however, some aspects of the graph-theoretic problem are uncertain. In these cases, it can be useful to deal with this uncertainty using the methods of fuzzy logic. This paper discusses the taxonomy of fuzzy graphs, formulates some standard graph-theoretic problems (shortest paths, maximum flow, minimum cut, and articulation points) in terms of fuzzy graphs, and provides algorithmic solutions to these problems, with examples.

K. P. Berkbigler, B. W. Bush, and J. F. Davis, "TRANSIMS Software Architecture for IOC-1," Report LA-UR-97-1242 (Los Alamos National Laboratory, 1997).

> This document describes the TRansportation ANalysis SIMulation System (TRANSIMS) software architecture and high-level design for the first Interim Operational Capability (IOC-1). Our primary goal in establishing the TRANSIMS software architecture is to lay down a framework for IOC-1. We want to make sure that the various components of TRANSIMS are effectively integrated, both for IOC-1 and beyond, so that TRANSIMS remains flexible, expandable, portable, and maintainable throughout its lifetime. In addition to outlining the high-level design of the TRANSIMS software, we also set forth the software development environment and software engineering practices used for TRANSIMS.

B. W. Bush, "TRANSIMS Input Editor System for IOC-1," Report LA-UR-97-1642 (Los Alamos National Laboratory, 1997).

> The TRANSIMS input editor provides a means for managing the TRANSIMS database, editing road network data, and setting up scenarios for simulation via its graphical user interface (GUI). It separates

the user from the lower-level layers of TRANSIMS software involved with data management. It has functions for manipulating data in the TRANSIMS database; for creating, importing, altering, validating, and viewing road network data; and for setting up simulation output tables. The input editor is integrated into the ArcView geographic information system (GIS) and the Oracle relational database. One can also customize or extend the input editor using the Avenue programming language.

K. P. Berkbigler and B. W. Bush, "TRANSIMS Simulation Output Subsystem for IOC-1," Report LA-UR-97-1226 (Los Alamos National Laboratory, 1997).

The TRANSIMS output subsystem collects data from a running microsimulation, stores the data for future use, and manages the subsequent retrieval of the data. It forms a layer separating the other subsystems from the actual data files so that the other subsystems do not need to access the data files at the physical level or deal with the physical location and organization of the files. This subsystem also allows the user to specify what data is collected and retrieved, and to filter it by space and time. The collection occurs in a distributed manner such that the subsystem's impact on the microsimulation performance is minimized; the retrieval provides a unified view of the distributed data.

K. P. Berkbigler and B. W. Bush, "TRANSIMS Network Subsystem for IOC-1," Report LA-UR-97-1580 (Los Alamos National Laboratory, 1997).

The TRANSIMS network representation provides access to detailed information about streets, intersections, and signals in a road network. It forms a layer separating the other subsystems from the actual network data tables so that the other subsystems do not need to access the data tables directly or deal with the format and organization of the tables. This subsystem allows the user to construct multiple subnetworks from the network database tables. It includes road network objects such as nodes (intersections), links (road/street segments), lanes, and traffic controls (signs and signals).

B. W. Bush, "TRANSIMS Database Subsystem for IOC-1," Report LA-UR-97-987 (Los Alamos National Laboratory, 1997).

The TRANSIMS database subsystem provides low-level services for accessing and modifying TRANSIMS data. It forms a layer separating the other subsystems from the actual data files so that the other subsystems do not need to access the data files at the physical level or deal with the physical location and organization of the files. This subsystem also organizes the data and supports a variety of metadata. It uses a relational model for the storage of data.

B. W. Bush, "A Tool for Drawing Undirected Graphs," Report LA-UR-96-2166 (Los Alamos National Laboratory, 1996).

The problem of laying out, or drawing, a graph arises in a wide variety of contexts. Automatically drawing computer network (e.g., LAN or WAN) configurations, object-oriented class diagrams, or database entity-relationship diagrams are examples of graph drawing. Estimating the layout of street networks containing some intersections with unknown locations is an example of the problem of drawing a graph. This paper discusses an algorithm for drawing general undirected graphs that relies on constructing a dynamical system analogous to the graph and evolving the state of the system to an equilibrium configuration. This configuration provides an aesthetically pleasing layout of the graph. We present an implementation of the algorithm as a C++ class. We also demonstrate the use of the class in a command-line executable program compilable on a variety of computer platforms as well as in an interactive 32-bit Windows program that animates the layout process.

B. W. Bush and J. R. Nix, "New Approach to the Interaction of Cosmic Rays with Nuclei in Spacecraft Shielding and the Human Body," Report LA-12452-MS (Los Alamos National Laboratory, 1993).

The interaction of high-energy cosmic rays with nuclei in spacecraft shielding and the human body is important for manned interplanetary missions and is not well understood either experimentally or theoretically. We present a new theoretical approach to this problem based on classical hadrodynamics for extended nucleons, which treats nucleons of finite size interacting with massive meson fields. This theory represents the classical analogue of the quantum hadrodynamics of Serot and Walecka without the assumptions of the mean-field approximation and point nucleons. It provides a natural covariant microscopic approach to collisions between cosmic rays and nuclei that automatically includes space-time non-locality and retardation, nonequilibrium phenomena, interactions among all nucleons, and particle production. Unlike previous models, this approach is manifestly Lorentz covariant and satisfies a priori the basic conditions that are present when cosmic rays collide with nuclei, namely an interaction time that is extremely short and a nucleon mean-free path, force range, and internucleon

separation that are all comparable in size. We review the history of classical meson-field theory and derive the classical relativistic equations of motion for nucleons of finite size interacting with massive scalar and vector meson fields.

L. Ransohoff, K. Knudsen, B. Bush, and R. Small, "Target Area Studies: Material Inventory and Smoke Properties," Report 1842 Vol. 4 (Pacific-Sierra Research Corporation, 1991).

B. W. Bush, L. M. Ransohoff, and R. D. Small, "Target Area Studies: Smoke Produced by a Nuclear Attack on the Soviet Union," Report 1842 Vol. 6 (Pacific-Sierra Research Corporation, 1991).

B. Bush, L. Ransohoff, R. McCoy, and R. Small, "Target Area Studies: Nuclear Winter Source Terms for Soviet Laydowns," Report 1842 Vol. 7 (Pacific-Sierra Research Corporation, 1991).

B. W. Bush, "Shape Fluctuations in Hot Rotating Nuclei," (Yale University Graduate School, 1990). *[cited 1 time]*

We present a unified theory of quadrupole shape fluctuations in highly excited rotating nuclei using the framework of the Landau Theory of shape transitions. The theory is applied to several experimental observables. Our major application is the study of giant dipole resonances (GDRs) built on hot rotating nuclei. With only two free parameters, fixed by the ground state properties, the model reproduces well experimental GDR cross-sections and angular correlations at any temperature and spin in the $90 \leq A \leq 170$ mass range for both spherical and deformed nuclei. A systematic study of the cross-section reveals that higher temperature cross-sections are dominated by large fluctuations (triaxial in particular) and are less sensitive to the equilibrium shape. To include non-adiabatic effects, we generalize our theory to describe time-dependent shape fluctuations using a stochastic approach based on the Langevin equation. This can produce motional narrowing of the resonance. Comparisons with experiments deviating from the adiabatic limit are used to determine the damping of quadrupole motion at finite temperature. Another application of the theory is in the study of E2 quasicontinuum spectra in warm nuclei, where it predicts enhancement of the B(E2), in accord with the experiment. Finally, we apply the fluctuation theory in improved calculations of nuclear level densities as a function of energy and spin using the static path approximation (SPA). Comparison with other calculations and experiments are made.

L. M. Ransohoff, G. H. Anno, B. W. Bush, and R. D. Small, "Topics in Nuclear Winter Source-Term Research: Composition of Residential Structures in the United States," Report 1761 Vol. 1 (Pacific-Sierra Research Corporation, 1987).

R. D. Small, B. W. Bush, and M. A. Dore, "Topics in Nuclear Winter Source-Term Research: Initial Smoke Distribution for Nuclear Winter Calculations," Report 1761 Vol. 3 (Pacific-Sierra Research Corporation, 1987).

B. W. Bush and R. D. Small, "Nuclear Winter Source-Term Studies: Ignition of Silo-Field Vegetation by Nuclear Weapons," Report 1628 Vol. 1 (Pacific-Sierra Research Corporation, 1986).

Smoke produced by the ignition and burning of live vegetation by nuclear explosions has been suggested as a major contributor to a possible nuclear winter. This report considers the mechanics of live vegetation ignition by a finite-radius nuclear fireball. For specified plant properties, the amount of fireball radiation absorbed by a plant community is calculated as a function of depth into the stand and range from the fireball. The spectral regions of plant energy absorption and the overlap with the emitted fireball thermal spectra are discussed. A simple model for the plant response to the imposed thermal load is developed. First, the temperature is raised; the change depends on the plant structure, moisture content, and plant canopy. Subsequent energy deposition desiccates the plant and finally raises its temperature to the threshold ignition limit. Results show the development of a variable depth ignition zone. Close to the fireball, ignition of the entire plant occurs. At greater distances (several fireball radii) portions of the plant are only partially desiccated, and sustained burning is less probable. Far from the burst, the top of the stand is weakly heated, and only a small transient temperature change results. An estimate of the smoke produced by an exchange involving the U.S. missile fields shows that the burning of live vegetation only slightly increases the total nonurban smoke production.

B. W. Bush and R. D. Small, "Nuclear Winter Source-Term Studies: The Classification of U. S. Cities," Report 1628 Vol. 2 (Pacific-Sierra Research Corporation, 1987). *[cited 3 times]*

A theory for classifying U.S. cities according to their burnable densities is developed. Urban land use, which is closely related to combustible loadings, is shown to be a classification correlate superior to the conventional measures of city rank such as population, urban area, or population density. Six

classes of cities are defined. The basic division is regional and the classification is shown to account for the demographic and economic characteristics that distinguish U.S. urban areas. Estimates of smoke production based on analysis of sample cities from each group would systematically account for differences in urban geographies.

M. A. Dore, B. W. Bush, G. H. Anno, and R. D. Small, "Nuclear Winter Source-Term Studies: Urban Area Analysis," Report 1628 Vol. 3 (Pacific-Sierra Research Corporation, 1988).

B. Bush, G. Anno, R. McCoy, R. Gaj, and R. Small, "Nuclear Winter Source-Term Studies: Fuel Loads in U. S. Cities," Report 1628 Vol. 4 (Pacific-Sierra Research Corporation, 1987).

B. W. Bush and R. D. Small, "Nuclear Winter Source-Term Studies: A Preliminary Analysis of Soviet Urban Areas," Report 1628 Vol. 5 (Pacific-Sierra Research Corporation, 1987).

B. W. Bush, M. A. Dore, G. H. Anno, and R. D. Small, "Nuclear Winter Source-Term Studies: Smoke Produced by a Nuclear Attack on the United States," Report 1628 Vol. 6 (Pacific-Sierra Research Corporation, 1987). *[cited 1 time]*

B. W. Bush and R. D. Small, "Smoke Produced by Nonurban Target-Area Fires Following a Nuclear Exchange," Report 1515 (Pacific-Sierra Research Corporation, 1985). *[cited 3 times]*

The amount of smoke that may be produced by wildland or rural fires as a consequence of a large-scale nuclear exchange is estimated. The calculation is based on a compilation of rural military facilities, identified from a wide variety of unclassified sources, together with data on their geographic positions, surrounding vegetation (fuel), and weather conditions. The ignition area (corrected for fuel moisture) and the amount of fire spread are used to calculate the smoke production. The results show a substantially lower estimated smoke production (from wildland fires) than in earlier nuclear winter studies. The amount varies seasonally and at its peak is less by an order of magnitude that the estimated threshold level necessary for a major attenuation of solar radiation.

B. W. Bush, "Track Reconstruction for Proton Decay," (California Institute of Technology, 1985).

Events from the 417 day IMB detector data sample are scanned visually to reconstruct tracks present, and their possibility of coming from proton decay assessed by considering their invariant mass and residual momentum. Events from Monte Carlo simulations of neutrino background in the detector are also analyzed similarly and compared to the IMB sample. No significant signal above background has been found, so lifetime limits for the four proton decay modes studied are presented.

Software

Brian W. Bush, Lori R. Dauelsberg, Michael H. Ebinger, Rene J. LeClaire, Dennis R. Powell, Steen Rasmussen, David R. Thompson, Cathy J. Wilson, Marc S. Witkowski, Andrew Ford, and Don Newsom, "Metropolitan Critical Infrastructure Model," Version 8.1 [LA-CC-04-088] (June 2004).

The Metropolitan Critical Infrastructure Model simulates the dynamics of fourteen critical infrastructures (agriculture, banking/finance, chemical industry, defense industrial base, emergency services, food, government, information/telecommunications, key resources, postal, public health transportation, water, energy) in urban areas at a highly aggregate level (i.e., total capacities/capabilities are represented instead of individual facilities). The purpose of the models is to simulate disruption scenarios, evaluate the consequences of such disruptions, and estimate the effectiveness of mitigation actions. The models include high-level infrastructure interdependencies, damage and recovery simulations, potential lost productivity and recovery cost, and aggregate market models. Dynamic processes like these are represented in the CIP/DSS infrastructure sector simulations by differential equations, discrete events, and codified rules of operation. The consequences are computed in terms of human health and safety, economic, public confidence, national security, and environmental impacts. Realistic databases are supplied separately from the software. The system is designed to help answer the following questions: (i) What are the consequences of attacks on infrastructure in terms of national security, economic impact, public health, and conduct of government—including the consequences that propagate to other infrastructures? (ii) Are there choke points in our Nation's infrastructures (i.e., areas where one or two attacks could have the largest impact)? What and where are the choke points? (iii) Incorporating consequence, vulnerability, and threat information into an overall risk assessment, what are the highest risk areas? (iv) What investment strategies can the U.S. make that will have the most impact in reducing overall risk?

Graham B. Booker, Brian W. Bush, Paul T. Giguere, Joe V. Holland, Steve P. Linger, Marvin L. Salazar, Cetin Unal, and Kenneth A. Werley, "Interdependent Energy Infrastructure Simulation System," Version 1.0 [LA-CC-02-078] (December 2002).

> The IEISS software models energy transmission network systems (such as electric power systems and natural gas pipelines) and simulates their physical behavior, including the interdependencies between systems (such as when the energy supplied by one system is used to operate components of another system). Each physical, logical, or functional entity in the model has a variety of attributes and behaviors that mimic its real-world counterpart. The software supports the analysis of the complex, non-linear, and emergent interactions between energy infrastructures at the state, regional, or national scale. (Databases are not supplied with the software, however.) Specifically, the simulation can be used to visualize the interconnectivity between different energy systems, predict the outcome of incidents affecting the networks, measure the economic effects of disruptions in service, assess system robustness under varied future plans and forecasts, and identify components critical for the operation of the systems.

B. W. Bush, "Java Agents Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998)].

B. W. Bush, "Java AWT Extension Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.1 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997), 2.3 (25 February 1997), 1.8 (19 January 1997)].

B. W. Bush, "Java BDE Wrapper Package," Version 8.0 (15 May 2000) [previous versions: 7.1 (14 March 1999), 7.0 (9 December 1998), 5.1 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997), 2.3 (25 February 1997), 1.8 (19 January 1997), 1.0 (11 November 1996)].

B. W. Bush, "Java Card Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.2 (3 June 1998)].

B. W. Bush, "Java Clustering Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998)].

B. W. Bush, "Java Data Structure Package," Version 8.0 (15 May 2000) [previous versions: 7.1 (14 March 1999), 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998)].

B. W. Bush, "Java Ephemeris Package," Version 8.0 (15 May 2000) [previous versions: 7.6 (14 March 1999), 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998)].

B. W. Bush, "Java Genetic Algorithms & Programming Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998), 3.5 (6 September 1997), 3.0 (1 August 1997)].

B. W. Bush, "Java Geography Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997), 2.3 (25 February 1997), 1.6 (19 January 1997)].

B. W. Bush, "Java Graph Theory Package," Version 8.0 (15 May 2000) [previous versions: 7.1 (14 March 1999), 7.0 (9 December 1998), 1.2 (1 June 1996)].

B. W. Bush, "Java Logic Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998)].

B. W. Bush, "Java Mathematics Package," Version 8.0 (15 May 2000) [previous versions: 7.1 (14 March 1999), 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998)].

B. W. Bush, "Java Metrics Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (14 March 1999), 7.2 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997), 2.3 (25 February 1997)].

B. W. Bush, "Java Relational Algebra Package," Version 8.0 (15 May 2000) [previous versions: 7.1 (14 March 1999)].

B. W. Bush, "Java Statistics Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998)].

B. W. Bush, "Java Tools Package," Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997)].

B. W. Bush, “Java Virtual Reality Modeling Language Package,” Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998), 5.0 (3 June 1998), 4.0 (6 January 1998), 3.0 (1 August 1997), 2.3 (25 February 1997), 1.3 (19 January 1997)].
B. W. Bush, “Java Visualization Package,” Version 8.1 (19 May 2000) [previous versions: 7.1 (14 March 1999), 7.0 (9 December 1998)].
B. W. Bush, “Java Wavelets Package,” Version 8.0 (15 May 2000) [previous versions: 7.0 (9 December 1998)].
B. W. Bush, “A Database Engine Wrapper for the BDE,” Version 3.3 (24 September 1996) [previous versions: 3.2 (29 July 1996), 3.0 (12 May 1996), 2.0 (14 July 1995), 1.3 (16 April 1995), 1.1 (4 February 1995), 1.0 (5 November 1994)].
B. W. Bush, “Windows RCS Application,” Version 2.3 (19 July 1996) [previous versions: 2.3 (19 July 1996), 2.0 (7 May 1996)].
B. W. Bush, “Redirected Process Classes,” Version 1.0 (7 May 1996).
B. W. Bush, “COM Support Classes,” Version 1.0 (7 May 1996).
B. W. Bush, “A Tool for Drawing Undirected Graphs,” Version 2.2 (9 April 1996).
B. W. Bush, “Collection Class Enhancements,” Version 2.0 (24 March 1996).
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B. W. Bush, “Smalltalk Metrics Classes for VSW3.10,” Version 1.0 (25 January 1996).